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The possibilities of using linear models in the automation of agricultural machinery driving

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Summary: As a result of developing computer technology very complex, nonlinear models of vehicles have started to appear. But an important disadvantage of a model with high degree of freedom is a great deal of data needed to describe the vehicle features. It is especially important while the model is being adapted to use at a preliminary design stage, when many data lack. Lacking and uncertain data decrease accuracy of results obtained by simulation and put usefulness of expenditure of work connected with the model building in question. The paper presents the possibility of using simple linear models of agricultural transport units in the systems supporting the work of the driver. Two different models were analyzed. The first is the structural model with two degrees of freedom, and the second model uses transmittance functions. The results obtained by computer simulation and by measurements were compared. The concept of the system using such models was presented.

Key words: agricultural machine, modeling, simulation, driver support.

INTRODUCTION

As a result of developing computer technology very complex, nonlinear models of vehicles have started to appear. But an important disadvantage of a model with high degree of freedom is a great deal of data needed to describe the vehicle features. It is especially important while the model is being adapted to use at a preliminary design stage, when many data lack. Lacking and uncertain data decrease accuracy of results obtained by simulation and put usefulness of expenditure of work connected with the model building in question. For such a case we made an attempt of using a comparatively simple model with little degree of freedom [].

The systems supporting a driver's work in an agricultural vehicle have a few basic functions. The relief operator's continuous monitoring and making correction of drive direction in addition to the controlling function of an agricultural machine is the most important [].

Realization of the tasks can be provided by appropriate controllers allowing for the keeping of a vehicle motion's stability and realization of this motion's assumed direction.[,].

A typical example of an agricultural vehicle is a water cart for transporting liquid waste (Fig. 1). There are issues connected with the behavior of the vehicle when it is driven on any curve. Due to the fact that the tractors currently can reach speed of 18 m·s $^{-1}$ (65 km/h), we should, in the kinematics of the whole system, take into account the lateral dynamic susceptibility of the front and rear suspension [].

However, it is the most convenient to consider the issue of impact of the suspension stiffness using an example of the widely-used in agriculture delivery vehicle [,]. An example is the Mitsubishi L200 (Fig. 2) in combination with a trailer. An important argument in favor of adopting it for the investigation is defining its stability by the standards. You can name here at least basic standards such as ISO 4138, ISO TR3888, ISO 6597, ISO 7975, ISO 9816, ISO 7401 and ISO 12021. For agricultural vehicles such standards have not been developedas yet, hence our interest in the set of car - trailer.

Dynamics and kinematics of the tested vehicle is presented in Fig. 3. It should be noted that on the diagram there is no semitrailer. It was introduced in order to obtain more clarity of motion equations and their analysis.

EQUATIONS OF MOTION

The basic equations of motion were derived after the adoption of the assumption that the transverse stiffness of the front and rear suspension obtained in the identifica-

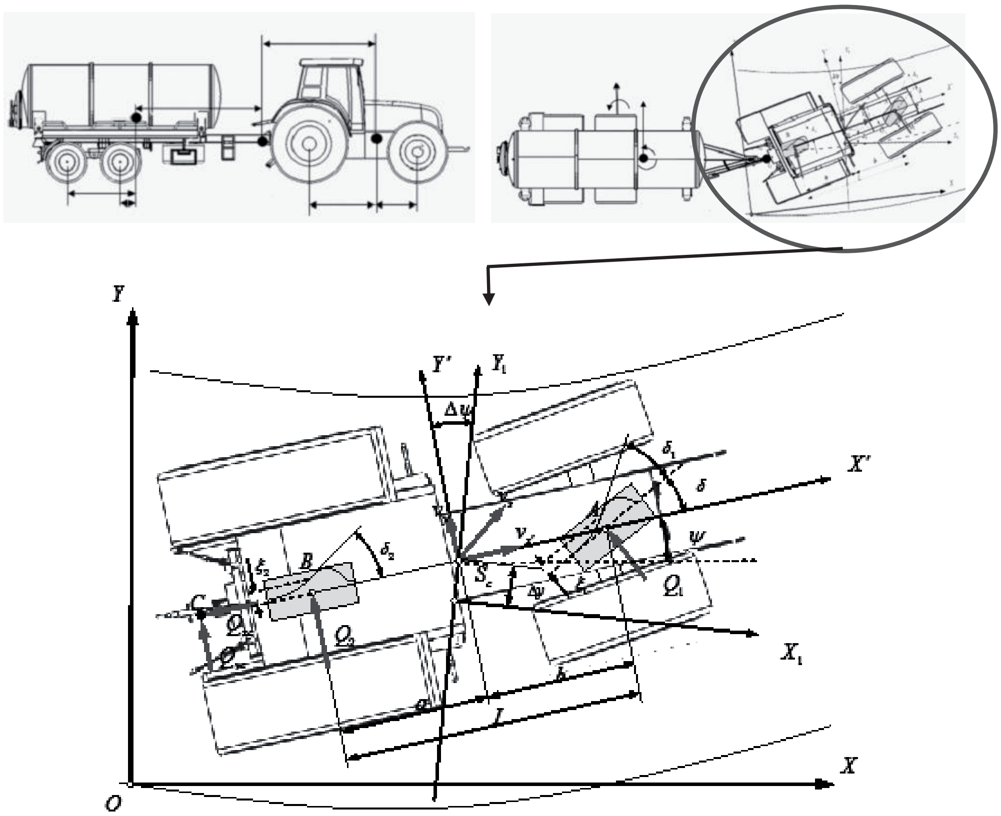

Fig. 1. Diagram of dynamics and kinematics of a tractor

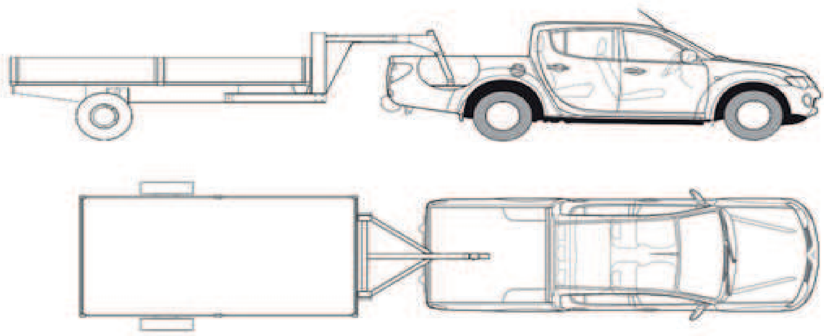

Fig. 2. The test object - Mitsubishi L200 car with trailer

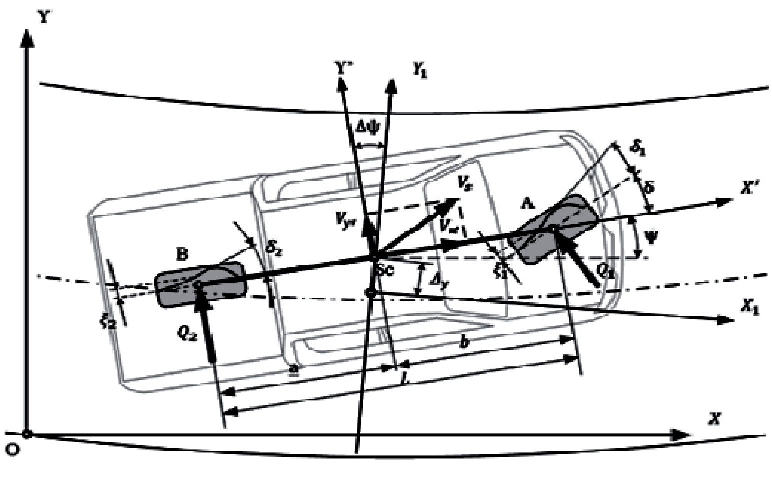

Fig 3. Diagram of dynamics and kinematics of the car Mitsubishi L200

tion process are included in tire stiffness [,]. Thus, for the presented scheme of dynamic and kinematic they can be written in the form of linear differential equations:

$$\begin{bmatrix}\ddot{\psi}\\ \beta\end{bmatrix}=\begin{bmatrix}-\dfrac{K_{\delta1}a^2+K_{\delta2}b^2}{I_{zz}v_s} & -\dfrac{K_{\delta1}a-K_{\delta2}b}{I_{zz}}\\ -\dfrac{mv_s^2+K_{\delta1}a-K_{\delta2}b}{mv_s^2} & -\dfrac{K_{\delta1}+K_{\delta2}}{mv_s}\end{bmatrix}\begin{bmatrix}\dot{\psi}\\ \beta\end{bmatrix}+\begin{bmatrix}\dfrac{K_{\delta1}a}{I_{zz}}\\ \dfrac{K_{\delta1}}{mv_s}\end{bmatrix}[\delta], \quad (1)$$

a - distance of the front axle of the vehicle from its center of gravity,
b - distance of the rear axle of the vehicle from its center of gravity,
$K_{\delta 1}$, $K_{\delta 2}$ - cornering coefficients of vehicle tyres,
m - mass of the vehicle,
v_s - vehicle speed,
I_{zz} - moment of inertia at the Z axis,
Ψ- yaw angle of the vehicle,
β - drifting angle of the vehicle.

The identification of the lateral stiffness of the front and rear suspension was performed using the measurements during double lane change meneuver and driving in a circle [].

Parametric identification was carried out to find the values of the parameters listed above, which would ensure compliance variables, obtained from the model and measurement results. The function describing the estimation error was non-negative function of estimated parameters [, ,].

COMPUTER SIMULATION

To validate the model we adopted the path in accordance with ISO TR3888 (Fig. 4), for which the forcing is shown in Fig. 5.

After the identification of the model, series of measurements of set car with semitrailer parameters during the driving were made. The obtained results were compared with the results from computer simulation. Based on the results, as illustrated in Fig. 6 and Fig. 7, we can conclude that the used model correctly predicts the behavior of the vehicle on the road.

Another type of linear models that can be used to describe the behavior of sets of agricultural vehicles are models using transmittance functions. Figure 8 shows a diagram of such a model taking into account the effect of the driver activity.

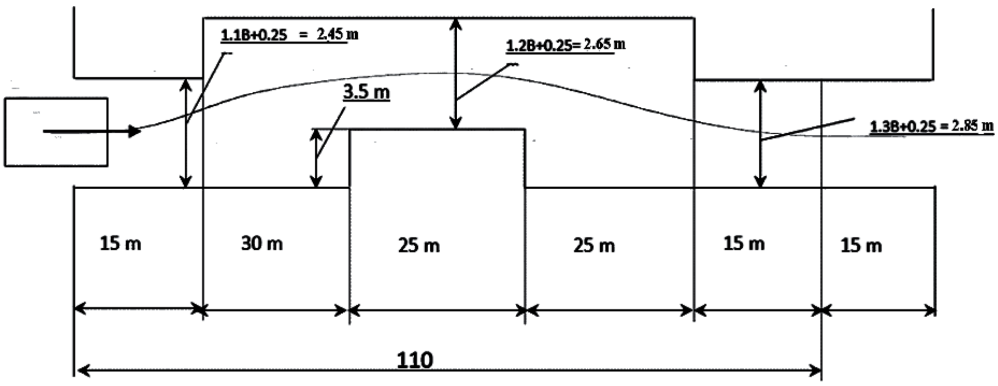

Fig. 4. Motion paths for the study of the vehicle behaviour during double lane change - ISO TR38888 []

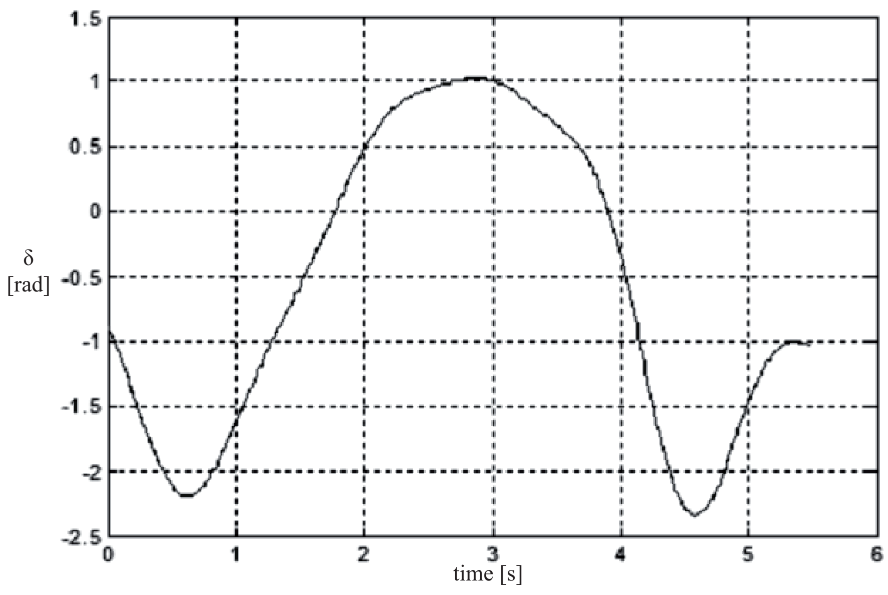

Fig. 5. Steered wheel angle δ recorded during the maneuver of double lane change

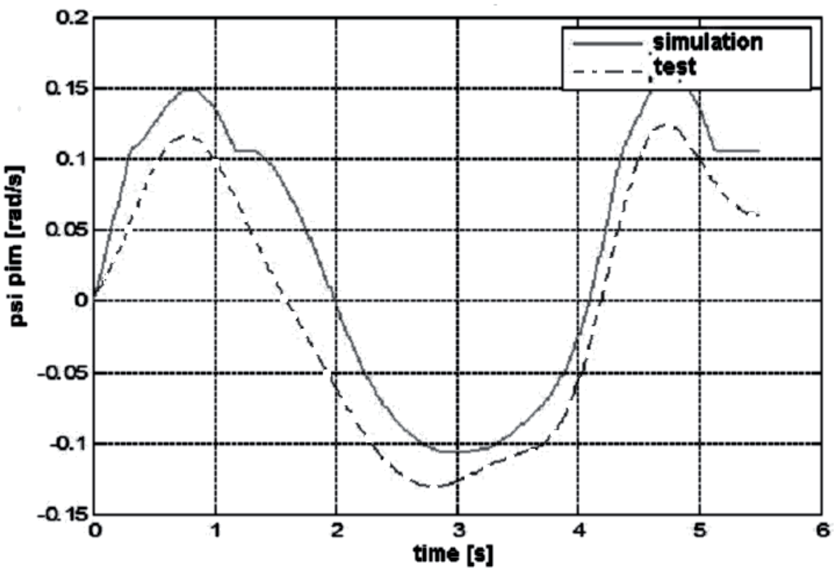

Fig. 6. Angular velocity of the vehicle deviation obtained from measurements and simulation

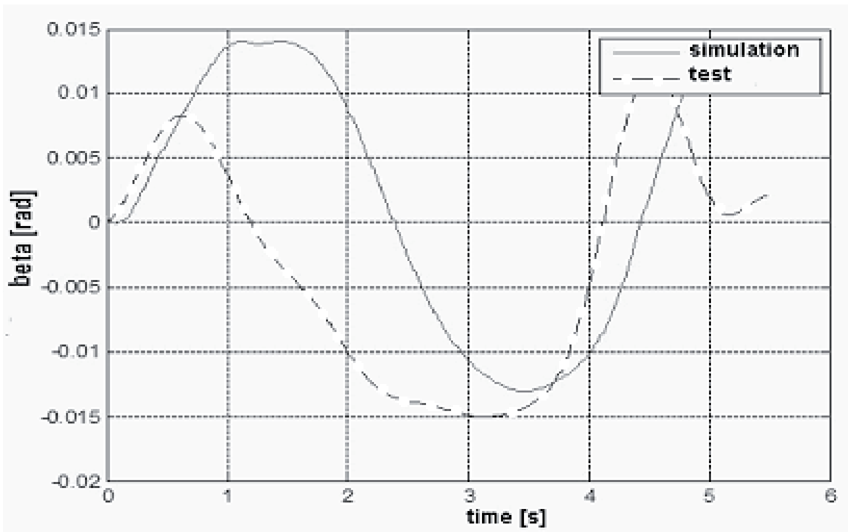

Fig. 7. Drift angle β of the vehicle obtained from measurements and simulation

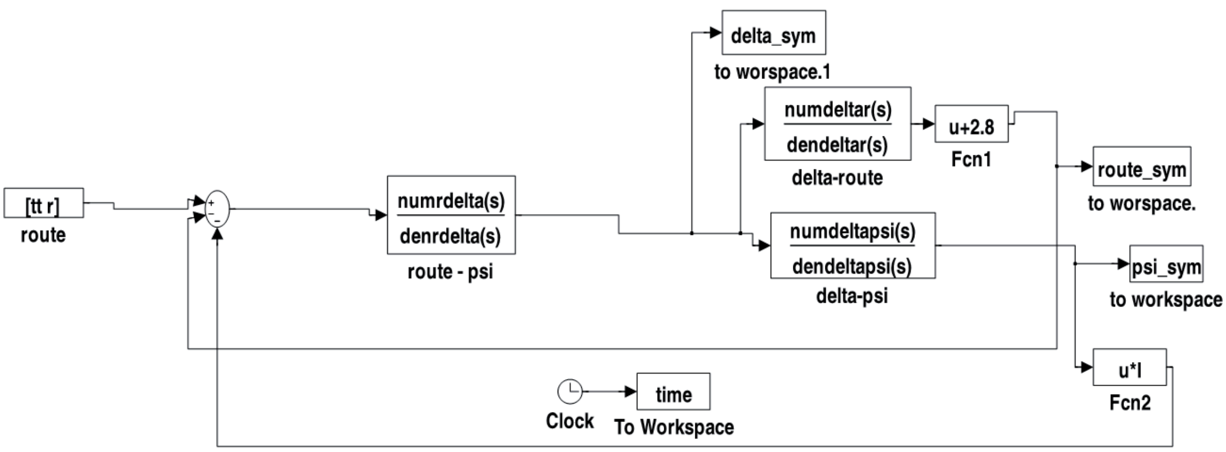

Fig. 8. Block diagram of the linear model using transmittance functions (in Matlab Simulink)

The transfer function can take into account some parameters of driving characteristics such as driving time delay with the aid of, for example, Pade aproximation [,]. The model can be used then for the analysis of a driver 's behaviour in the function of a driver's effort [,].

After identifying the transfer function the model allows to get high compatibility between the results obtained from measurements and from simulation (Fig. 9 and Fig. 10).

THE CONCEPT OF CONTROL OF THE VEHICLES

Fig. 11 shows the scheme of control of the vehicle in which signals from the sensors [] are used to correct the car trajectory. The sensors are used to enable the obtainment of data on the actual position of the vehicle. The block named "Guidance system", based on predictive simulation, generates steering angle δ of the wheels.

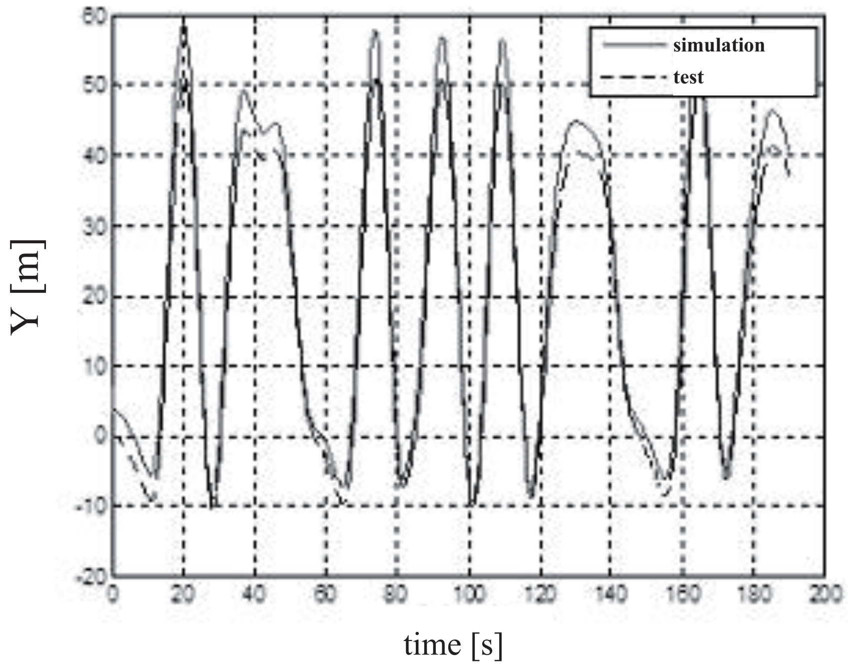

Fig 9. Y coordinate of the trajectory obtained from simulation using a block diagram of Fig. 8 and from the measurement

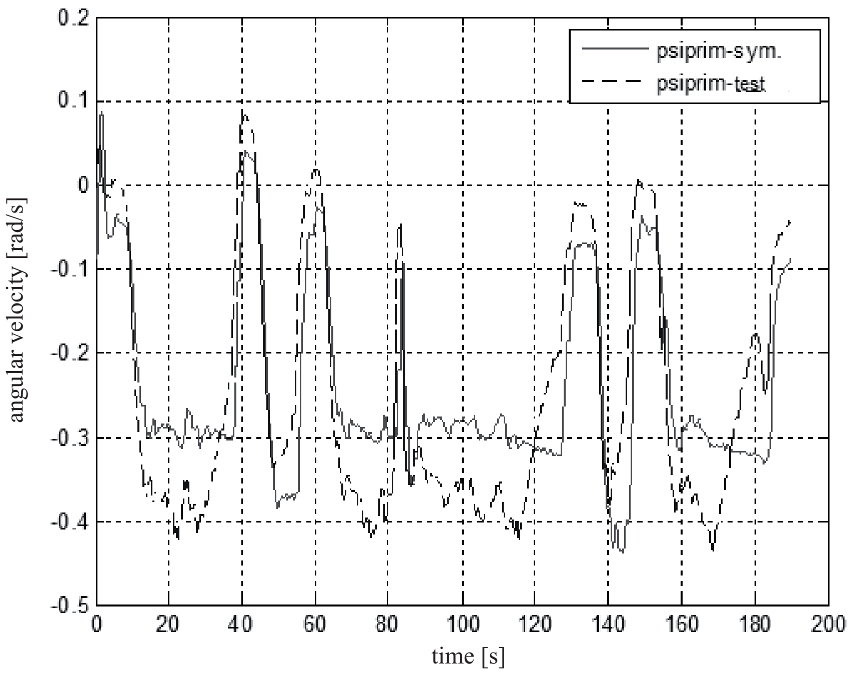

Fig. 10. The course of the angular velocity of deflection angle ψ obtained from simulation using a block diagram of Fig. 8 and from the test

It is implemented by means of hydraulic or mechanical device installed in the vehicle (block Controller on Fig. 11). The response of the vehicle to change of the angle δ depends on the properties of the vehicle (Vehicle Dynamics block). Based on the values of the lateral deflection y and the angle Ψ (Fig. 13), lateral deviation of the vehicle in the vehicle reference point (indicated in Fig. 13 as C) is calculated (L is the distance between the axles of the vehicle) [].

Guidance block is presented in detail in Fig. 12. Steering angle δ is calculated on the basis of the current vehicle position relative to the set path (angle Φ on Fig. 13) [], data describing the state of the vehicle (speed, acceleration) obtained from the sensors and the linear model of the vehicle [].

THE CONCLUSIONS

Based on computer simulations it can be accepted that the two presented linear models meet the conditions of conformity with the test results:

– the deterministic flat model with two degrees of freedom,
– the stochastic model based on the identified functions of transmittance.

This suggests that such models can be used in the study of motion and stability in systems supporting the driver's work in agricultural vehicles as well as the driver's behaviour.

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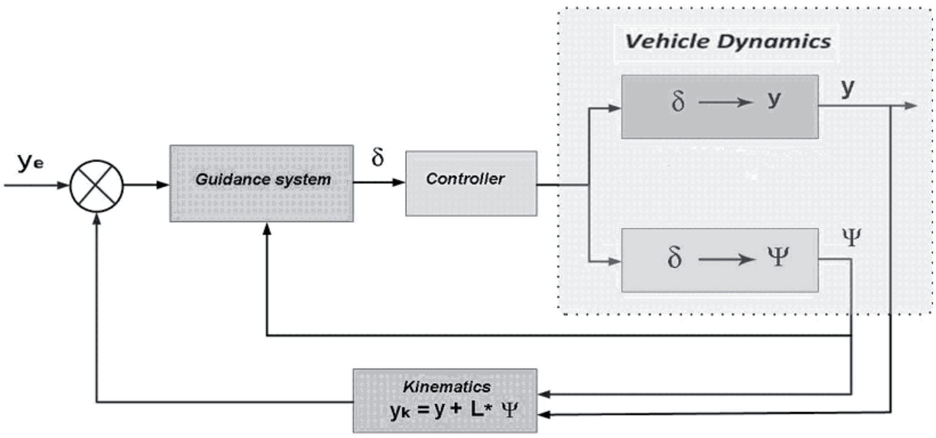

Fig 11. Scheme of vehicle control

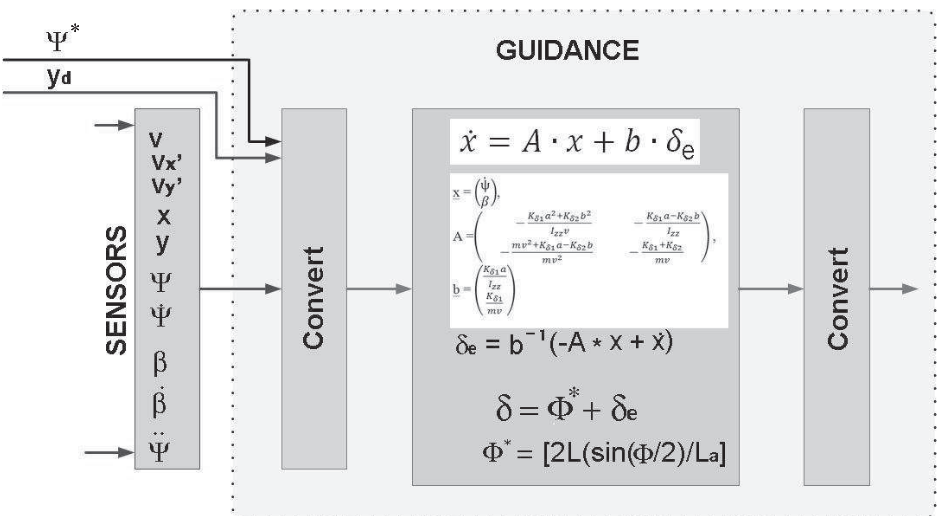

Fig. 12. Diagram of block of vehicle control

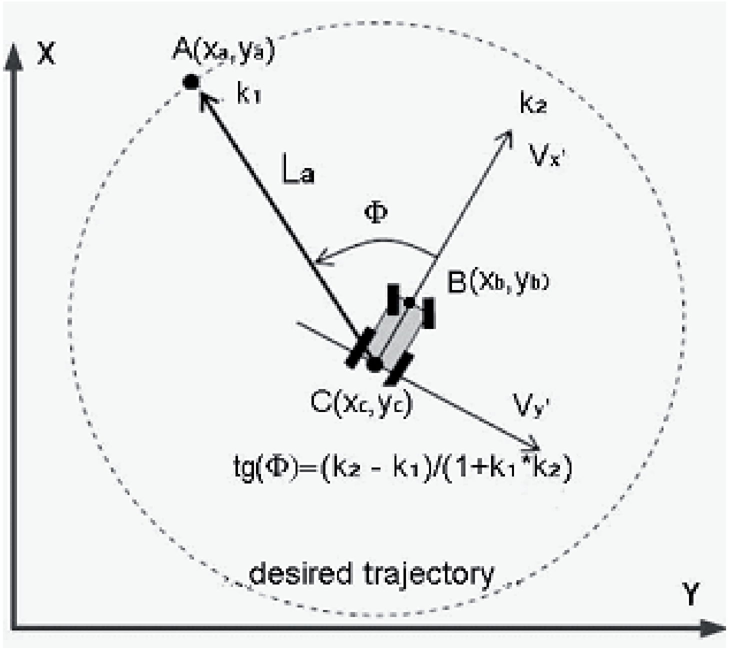

Fig. 13. The pure pursuit method of calculating the vehicle position relative to a point lying on the trajectory []

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MOŻLIWOŚCI ZASTOSOWANIA MODELI LINIOWYCH
W AUTOMATYZACJI KIEROWANIA
MASZYNAMI ROLNICZYMI

S t r e s z c z e n i e. W wyniku zwiększania się możliwości obliczeniowych komputerów w badaniach zachowania pojazdów zaczęły pojawiać się ich złożone, nieliniowe modele. Jednak istotną ich wadą jest konieczność zebrania dużej liczby danych opisujących własności modelowanych pojazdów. Jest to szczególnie istotne, gdy model jest przeznaczony do wykorzystania na wstępnym etapie projektowania, gdy wielu danych jeszcze brak. Brakujące i niepewne dane zmniejszają dokładność wyników obliczeń symulacyjnych, co stawia w wielu przypadkach pod znakiem zapytania użyteczność takich modeli.

W prezentowanym artykule przedstawiamy propozycję wykorzystania prostych, liniowych modeli w systemach wspomagających pracę kierowcy maszyny rolniczej lub rolniczego zestawu transportowego. Poddano analizie dwa różne modele. Pierwszy to model strukturalny o dwóch stopniach swobody, a drugi model wykorzystuje funkcje transmitancji. Porównano rezultaty uzyskane za pomocą obliczeń symulacyjnych i za pomocą pomiarów. Przedstawiono koncepcję systemu wykorzystującego takie modele.

Słowa kluczowe: maszyny rolnicze, modelowanie, symulacja, wspomaganie kierowcy.